Effects of Ocean Wind, Foam/Spray and Atmosphere on Four Stokes Parameters in Passive Polarimetric Remote Sensing of the Ocean Based on Numerical Simulations and Analytic Theory

Leung Tsang
Department of Electrical Engineering
Box 352500, University of Washington
Seattle, WA 98195
phone: (206) 685-7537 fax: (206) 543-3842 email: tsang@ee.washington.edu

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ABSTRACT

The research last year consisted of three parts:

A. Microwave emission and scattering of foam based on Monte Carlo simulations of dense media;

B. Polarimetric passive microwave remote sensing of wind vectors with foam-covered, rough ocean surfaces;

C. Brightness temperature of ocean with wind based on paralleled code of MoM with RWG basis function.

A: MICROWAVE EMISSION AND SCATTERING OF FOAM BASED ON MONTE CARLO SIMULATIONS OF DENSE MEDIA

Emissvities of ocean surfaces are affected by the presence of foam. Recently, field experiments have been conducted at the Chesapeake Bay Detachment to study the foam emissivity as a function of polarization, observation angle and frequencies at 10.8 GHz and 36.5 GHz. The measurements exhibit important frequency dependence [1]. The results are not explained by simple mixing formulae nor past empirical models. In particular, the emissivities at 10.8 GHz are observed to be comparable to that of 36.5 GHz. Foam is a mixture of air bubbles and sea water. The bubbles range from sizes of hundreds of microns to millimeters. We conduct theoretical modeling based on modeling the microstructure of foam taking into account bubble size, fractional volume of water to rigorously study the emission, absorption and scattering properties and to account for the observed frequency dependence and polarimetric dependence of emissivities. In a previous paper, wave scattering and emission in a medium consisting of densely packed coated particles are solved by using the quasicrystalline approximation in combination with the dense-media radiative-transfer theory [2] (DMRT). Recently, we applied Monte Carlo simulations of solutions of Maxwell equations of densely packed coated particles to analyze the microwave emission and scattering of foam. The absorption, scattering and extinction coefficients are calculated. These quantities are then used in dense-media radiative-transfer theory to calculate the microwave emissivity. In order to have high density packing, we use a face-centered-cubic (fcc) structure to place the air bubbles. Salient features of the numerical results are (1) the absorption coefficients at 10.8 GHz are appreciable and (2) the emissivities at 10.8 GHz and 36.8 GHz are comparable. These features are consistent with experimental measurements. Comparisons

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are made with experimental measurements for vertical and horizontal polarizations, as shown in Fig. 1 and Fig. 2 and good agreement can be seen. Simulation results of emissivity with typical parameters of foam at 10.8 GHz and 36.5 GHz are illustrated in Reference [3]

B: POLARIMETRIC PASSIVE MICROWAVE REMOTE SENSING OF WIND VECTORS WITH FOAM-COVERED ROUGH OCEAN SURFACES

Polarimetric microwave remote sensing means that all four Stokes parameters are measured. There has been an increasing interest in the applications of polarimetric microwave radiometers for ocean-wind remote sensing. Recently, we developed a physically based approach taking into account the micro-structure of foam, which treats the foam as densely packed air bubbles coated with thin seawater. It was shown that the polarization and frequency of the brightness temperatures depend on the physical microstructure properties of foam and the foam layer thickness. Guo et al. [2] used the Quasi-Crystalline Approximation (QCA) model for foam, while Chen et al. [3] used the Monte Carlo simulations. Controlled experiments of radiometric measurements of foam microwave emissions have also been made [1].

In this work [4], the polarimetric microwave emissions from wind-generated, foam-covered rough ocean surfaces are studied, as indicated in Fig. 3. The dense media model of foam is applied to calculate the values of the complex effective propagation constants, the extinction coefficients and the albedo. These are used to describe the characteristics of the foam layer. The effects of boundary roughness of ocean surface are included in the boundary conditions of DMRT by using the second-order small-perturbation method (SPM) describing the bistatic reflection coefficients between foam and ocean. The small-scale, wind-generated sea surfaces are generated by anisotropic directional spectra. The iterative method is employed to solve dense-media radiative-transfer equations. Theoretical results of four Stokes brightness temperatures with typical parameters of foam based on Monte Carlo simulations in passive remote sensing at 10.8 GHz, 19 GHz and 36.5 GHz are illustrated. The first two Stokes parameters are increased with the presence of foam, and the third and fourth parameters are reduced. The first two Stokes parameters are even functions of ϕ, while the last two parameters are odd functions of ϕ. Emissions with various wind speeds and foam layer thicknesses are also studied. In Fig. 4, we plot the brightness temperature of four Stokes parameters as functions of thickness of foam layer. As the thickness of the foam layer increases, *Tv* and *Th* will increase correspondingly and then saturate at a particular thickness of the foam layer. On the other hand, *U* and *V* components will decrease to zero. The details of results and discussions are described in [4].

C: BRIGHTNESS TEMPERATURE OF OCEAN WITH WIND BASED ON PARALLEL CODE OF MOM WITH RWG BASIS FUNCTION

Recently, numerical simulations of solutions of Maxwell equations for rough surface scattering have been performed. Most of the ocean surface simulations are concerned with radar active remote sensing. There is less work on simulations for passive remote sensing. One reason is that passive remote sensing requires much more accuracy than active remote sensing. In active remote sensing, the scattering is measured in decibel scale. For passive remote sensing, the major output is the difference of emissivity or brightness temperature between a rough ocean surface and a flat ocean surface. The difference in emissivity can be as small as 0.002 or a brightness temperature of $0.5K$ using a physical temperature of $283K$. Such a strict demand of accuracy is not needed for active remote sensing. For example, numerical simulations can give good results in active remote sensing in dB scale and give

poor results in passive remote sensing, because energy conservation is not obeyed well in the simulations. Thus the numerical simulation method and approximations that are applied to active remote sensing may not be suitable for passive remote sensing because of the large difference in accuracy requirements. Another difficulty for ocean surfaces is that the relative permittivity can be as high as 28.9541+i36.8430 at 19 GHz. For lossy dielectric rough surfaces with high permittivity, there can be rapid spatial variations of the dielectric medium Green's function and surface fields. This requires very accurate integration for near field interaction in lower media to calculate impedance matrix elements. To better model rough surfaces, we make use of the RWG triangular basis function that ensures continuity of surface fields between basis functions. High accuracy has been achieved.

In the ocean spectrum, the upper band limit k_U corresponds to the high frequency part of the ocean spectrum. As k_U becomes larger, the rms slope of rough surfaces will increase, because the fine scale structures have larger rms slope. More number of triangles are required for fine scale structures. We will use the sparse-matrix/canonical-grid (SM/CG) method to solve the matrix equation, in which the far-interaction portion of matrix-vector multiplication in the iterative solution is performed by the fast Fourier transforms (FFTs). This is achieved by the Taylor series expansions of the spatial Green's functions about the uniformly spaced canonical grid points overlaying the triangular discretization. The SM/CG method has computational complexity of O(NlogN). Being FFT-based facilitates the implementation for parallel computation. Simulations for solving the large number of unknowns will be performed by using parallel computing, while the energy conservation is checked to ensure the accuracy.

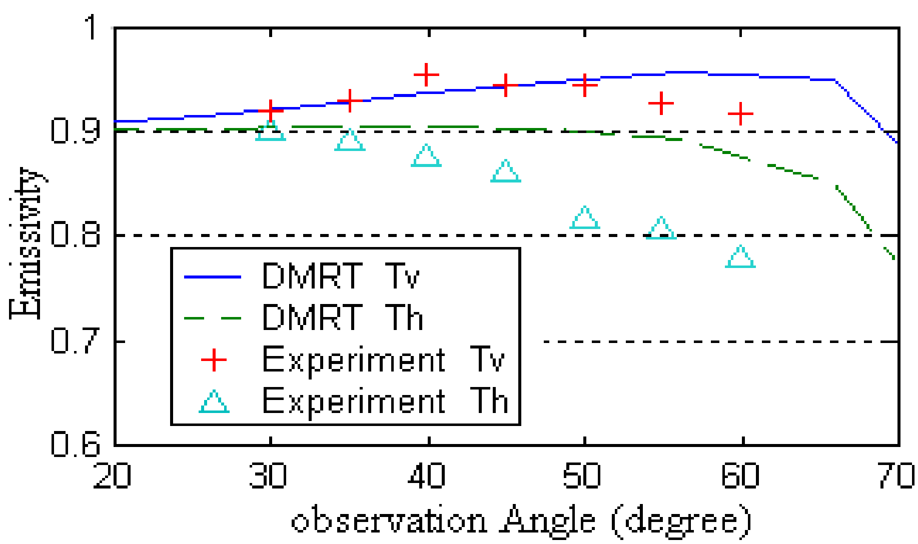

Fig. 1. Comparison between the simulation results and the measurements of the microwave emissivity at 10.8GHz for horizontal polarization and vertical polarization, respectively.

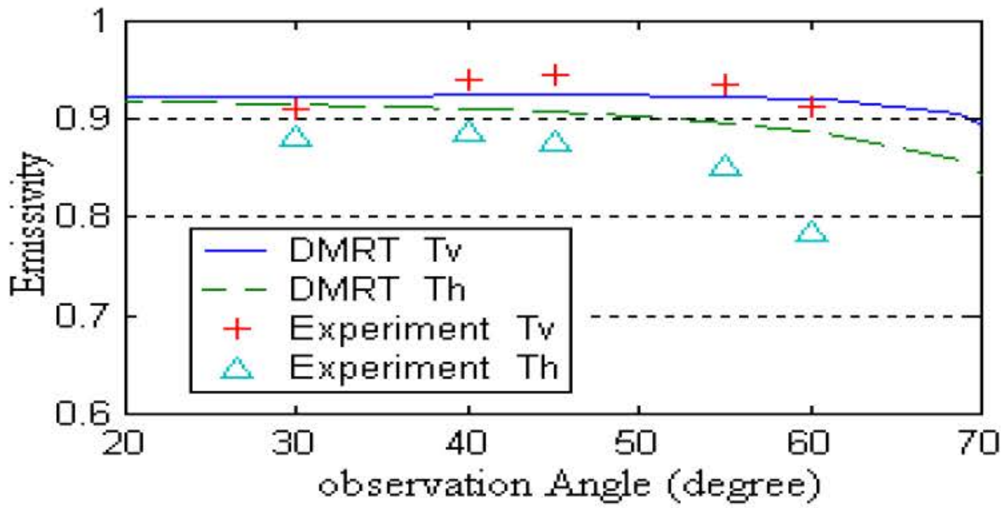

Fig. 2. Comparison between the simulation results and the measurements of the microwave emissivity at 36.5GHz for horizontal polarization and vertical polarization, respectively.

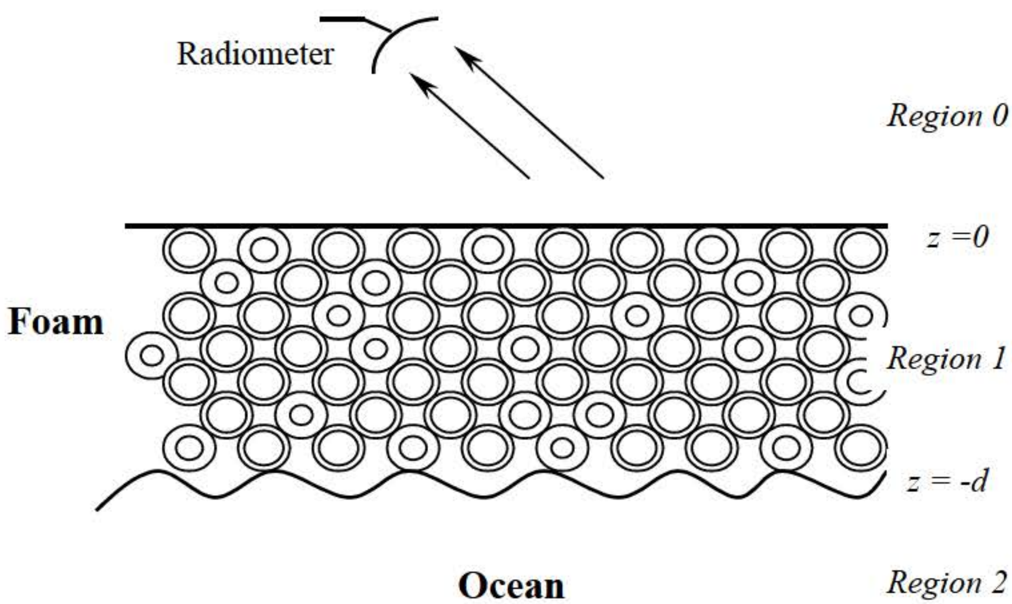

Fig. 3. Geometrical configuration for thermal emission from foam-covered rough ocean surface.

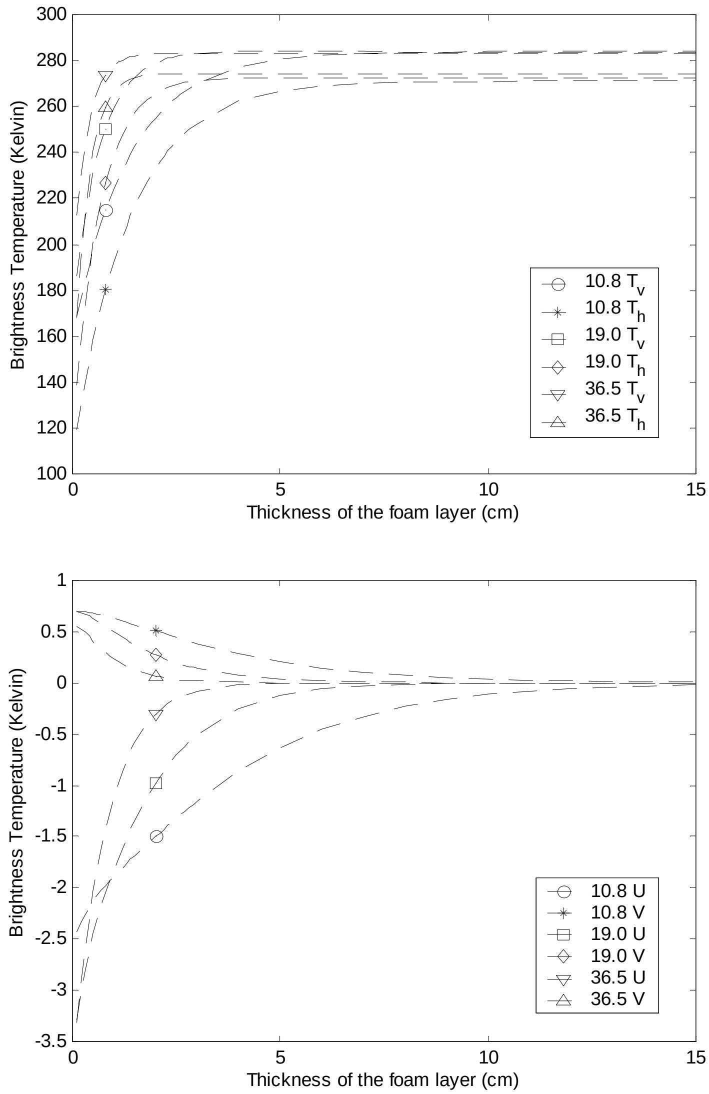

Fig. 4. Brightness temperature as a function of the thickness of the foam layer at aspect angle θ = 53 degree, at 10.8GHz, 19GHz and 36.5GHz.

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